10.5 LIMIT STATES AND RESISTANCE FACTORS

10.5.1 General

Revise as follows:

The limit states shall be as specified in Article 1.3.2; geotechnical foundation design ~~specific~~ provisions are contained in this Section.

Foundations for intermediate supports shall be proportioned so that the factored resistance is not less than the effects of the factored loads specified in Section 3.

Foundations for end supports shall be designed using the SERVICE LIMIT STATE I-IV loads, as provided in these Specifications, and the Service Load Design method provided in the *Caltrans Bridge Design Specifications (2000)*, dated November 2003.

10.5.2 Service Limit States

10.5.2.1 General

Revise the 1st paragraph as follows:

Foundation design at the service limit state shall include:

- Settlements
- Horizontal movements
- Overall stability, and
- Total s~~S~~cour at the base ~~design~~ flood

C10.5.2.1

Revise the 3rd paragraph as follows:

The base ~~design~~ flood for scour is defined in Article 2.6.~~4.4.2~~, and is specified in Article 3.7.5 as applicable at the service limit state.

10.5.3 Strength Limit States

10.5.3.1 General

Revise the 2nd paragraph as follows:

The design of all foundations at the strength limit state shall consider:

- Structural resistance and
- Loss of lateral and ~~vertical~~ axial support due to total scour at the base ~~design~~ flood event.

C10.5.3.1

Revise the 4th paragraph as follows:

The base ~~design~~ flood ~~event~~ for scour is defined in Article 2.6.~~4.4.2~~, and is specified in Article 3.7.5 as applicable at the strength limit state.

10.5.4 Extreme Events Limit States

Revise as follows:

Foundations shall be designed for extreme events as applicable.

C10.5.4

Revise the 2nd paragraph as follows:

Extreme events include ~~the check flood for scour~~, vessel and vehicle collision, seismic loading, and other site-specific situations that the Engineer determines should be included. Scour should be considered with extreme events as per Article 3.4.1

10.5.5 Resistance Factors

10.5.5.1 Service Limit States

Revise the 2nd paragraph as follows:

A resistance factor of 1.0 shall be used to assess the ability of the foundation to meet the specified deflection criteria after scour due to the base ~~design~~ flood.

10.5.5.2 Strength Limit States

10.5.5.2.1 General

Revise as follows:

Resistance factors for different types of foundation systems at the strength limit state shall be taken as specified in Articles 10.5.5.2.2, 10.5.5.2.3, and 10.5.5.2.4~~, unless regionally specific values or substantial successful experience is available to justify higher vales~~.

The foundation ~~resistance~~ after scour due to the base ~~design~~ flood shall provide adequate ~~foundation~~ factored resistance using the resistance factors given in this article.

C10.5.5.2.1

Revise as follows:

~~Regionally specific values should be determined based on substantial statistical data combined with calibration or substantial successful experience to justify higher values.~~ Smaller resistance factors should be used if site or material variability is anticipated to be unusually high or if design assumptions are required that increase design uncertainty that have not been mitigated through conservative selection of design parameters. When a single pile or drilled shaft supports a bridge pier, reduction of the resistance factors in Articles 10.5.5.2.3 and 10.5.5.2.4 should be considered.

Certain resistance factors in Articles 10.5.5.2.2, 10.5.5.2.3 and 10.5.5.2.4 are presented as a function of soil type, e.g., cohesionless or cohesive ~~sand or clay~~. Many ~~N~~naturally occurring soils do not fall neatly into these two classific ations. In general, the terms ~~"sand" and~~ "cohesionless soil" or “sand” may be connoted to mean drained conditions during loading, while ~~"clay" or~~ "cohesive soil" or “clay” implies undrained conditions in the short-term. For other or intermediate soil classifications, such as clayey sand or silts ~~or gravels~~, the designer should choose, depending on the load case under consideration, whether the resistance provided by the soil in the short term will be a drained, undrained, or a combination of the two strengths and select the method of computing resistance and associated resistance factor accordingly.

In general, resistance factors for bridge and other structure design have been derived to achieve a reliability index, β, of 3.5, an approximate probability of failure, P_f, of 1 in 5,000. However, past geotechnical design practice has resulted in an effective reliability index, β, of 3.0, or an approximate probability of a failure of 1 in 1,000, for foundations in general, and for highly redundant systems, such as pile groups, an approximate reliability index, β, of 2.3, an approximate probability of failure of 1 in 100 *(Zhang et aI., 2001; Paikowsky et aI., 2004; Allen, 2005).* ~~If the resistance factors provided in this article are adjusted to account for regional practices using statistical data and calibration, they should be developed using the β−values provided above, with consideration given to the redundancy in the foundation syetem.~~

For bearing resistance, lateral resistance, and uplift calculations, the focus of the calculation is on the individual foundation element, e.g., a single pile or drilled shaft. Since these foundation elements are usually part of a foundation unit that contains multiple elements, failure of one of these foundation elements usually does not cause the entire foundation unit to reach failure, i.e., due to load sharing and overall redundancy. Therefore, the reliability of the foundation unit is usually more, and in many cases considerably more, than the reliability of the individual foundation element. Hence, a lower reliability can be successfully used for redundant foundations than is typically the case for the superstructure.

Note that not all of the resistance factors provided in this article have been derived using statistical data from which a specific β value can be estimated, since such data were not always available. In those cases, where adequate quantity and/or quality of data were not available, resistance factors were estimated through calibration by fitting to past allowable stress design safety factors, e.g. the *Caltrans Bridge Design Specifications (2000)*, dated November 2003. ~~AASHTO *Standard Specifications for Highway Bridges (2002).*~~

Additional discussion regarding the basis for the resistance factors for each foundation type and limit state is provided in Articles *10.5.5.2.2*, *105.5.2.3*, and 10.5.5.2.4. Additional, more detailed information on the development of some of the resistance factors for foundations provided in this article, and a comparison of those resistance factors to previous Allowable Stress Design practice, e.g., AASHTO *(2002)*, is provided in Allen *(2005)*.

Scour design for the base ~~design~~ flood must satisfy the requirement that the factored foundation resistance after scour is greater than the factored load determined with the scoured soil removed. The resistance factors will be those used in the Strength Limit State, without scour.

10.5.5.2.2 Spread Footings

Revise as follows:

The resistance factors provided in Table 10.5.5.2.2-1 shall be used for strength limit state design of spread footings~~, with the exception of the deviations allowed for local practices and site specific considerations in Article 10.5.5.2.~~

C10.5.5.2.2

Revise Table 10.5.5.2.2-1 as follows:

Table 10.5.5.2.2-1 Resistance Factors for Geotechnical Resistance of Shallow Foundations at the Strength Limit State

NOMINAL RESISTANCE	RESISTANCE DETERMINATION METHOD/~~SOIL~~/CONDITIONS	RESISTANCE FACTOR	
Bearing ~~Resistance~~ in Compression	Theoretical Method – (Munfakh et al, 2001), in ~~clay~~ cohesive soils	φ_b	0.50
	Theoretical Method – (Munfakh et al, 2001), in ~~sand~~ cohesionless soils based on drained friction angle from correlations to the results of: ~~using~~ – CPT ~~using~~ –SPT or Other Field Tests		 0.50 0.45
	Semi-Empirical Methods– (Meyerhof, ~~1957~~ 1956), in cohesionless soil ~~all soils~~		0.45
	Footings on rock		0.45
	Plate Load Test		0.55
Sliding	Precast concrete on sand	φ_τ	0.90
	Cast-in-place concrete on sand		0.80
	Cast-in-place or pre-cast concrete on clay		0.85
	Soil on soil		0.90
	Passive earth pressure component of sliding resistance	φ_{ep}	0.50

10.5.5.2.3 Driven Piles

Delete the entire Article 10.5.5.2.3 and replace with the following:

Resistance factors for driven piles shall be selected from Table 10.5.5.2.3-1.

C10.5.5.2.3

Delete the entire Commentary to Article 10.5.5.2.3 and replace with the following:

The resistance factors in Table 10.5.5.2.3-1 are based on engineering judgment, and past ASD and LFD practice.

Replace Table 10.5.5.2.3-1 as follows:

Table 10.5.5.2.3-1 Resistance Factors for Driven Piles

NOMINAL RESISTANCE	RESISTANCE DETERMINATION METHOD/CONDITIONS	RESISTANCE FACTOR	
Axial Compression or Tension	All resistance determination methods, and soils and rock	φ_{stat} , φ_{dyn} , φ_{qp}, φ_{qs}, φ_{bl}, φ_{up} , φ_{ug} , φ_{load},	0.70
Lateral ~~Horizontal~~ Resistance ~~of Single Pile or Pile Group~~	All soils and rock		1.0
Pile Drivability Analysis	Steel Piles	φ_{da}	See the provisions of Article 6.5.4.2
	Concrete Piles		See the provisions of Article 5.5.4.2.1
	Timber Piles		See the provisions of Articles 8.5.2.2
	In all three Articles identified above, use φ identified as “resistance during pile driving”		
Structural Limit States	Steel Piles	See the provisions of Article 6.5.4.2	
	Concrete Piles	See the provisions of Article 5.5.4.2.1	
	Timber Piles	See the provisions of Article 8.5.2.2 and 8.5.2.3	

10.5.5.2.4 Drilled Shafts

Delete the entire Article 10.5.5.2.4 and replace with the following:

Resistance factors for drilled shafts shall be selected from Table 10.5.5.2.4-1.

C10.5.5.2.4

Delete the entire Commentary to Article 10.5.5.2.4 and replace with the following:

The resistance factors in Table 10.5.5.2.4-1 are based on engineering judgment, and past ASD and LFD practice.

The maximum value of the resistance factors in Table 10.5.5.2.4-1 are based on an assumed normal level of field quality control during shaft construction. If a normal level of quality control can not be assured, lower resistance factors should be used

The mobilization of drilled shaft tip resistance is uncertain as it depends on many factors including soil types, groundwater conditions, drilling and hole support methods, the degree of quality control on the drilling slurry and the base cleanout, etc. Allowance of the full effectiveness of the tip resistance should be permitted only when cleaning of the bottom of the drilled shaft hole is specified and can be acceptably completed before concrete placement.

Replace Table 10.5.5.2.4-1 as follows:

Table 10.5.5.2.4-1 Resistance Factors Geotechnical Resistance of Drilled Shafts

NOMINAL RESISTANCE	RESISTANCE DETERMINATION METHOD/SOIL CONDITIONS	RESISTANCE FACTOR	
Axial Compression and Tension or uplift	All soils, rock and IGM	φ_{stat}, φ_{up}, φ_{bl}, φ_{ug}, φ_{load}, φ_{upload} φ_{qp}, φ_{qs},	0.70
Lateral Geotechnical Resistance	All soils and rock		1.0

10.5.5.3 Extreme Limit States

10.5.5.3.1 General

Design of foundations at extreme event limit states shall be consistent with the expectation that structure collapse is prevented and that life safety is protected.

10.5.5.3.2 Scour

Delete entire Article:

~~The foundation shall be designed so that the nominal resistance remaining after the scour resulting from the flood (see Article 2.6.4.4.2) provides adequate foundation resistance to support the unfactored Strength Limit States loads with a resistance factor of 1.0. For the uplift resistance of piles and shafts, the resistance factor shall be taken as 0.80 or less.~~

~~The foundation shall resist not only the loads applied from the structure but also any debris loads occurring during the flood event.~~

C10.5.5.3.2

Revise the 1st paragraph as follows:

~~The axial nominal strength after scour due to the check flood must be greater than the unfactored pile or shaft load for the Strength Limit State loads. The specified resistance factors should be used provided that the method used to compute the nominal resistance does not exhibit bias values for the pile resistance prediction methods. See Paikowsky et al. (2004) regarding bias values for pile resistance prediction methods.~~ <u>See Commentary to Article 3.4.1, Extreme Events, and Article 3.7.5.</u>

10.5.5.3.3 Other Extreme Limit States

Revise as follows:

Resistance factors for extreme events for extreme limit state, including the design of foundations to resist earthquake, ice vehicle or vessel impact loads, shall be taken as 1.0. ~~For the uplift resistance of piles and shafts, the resistance factor shall be taken as 0.80 or less.~~

C10.5.5.3.3

Delete the entire Commentary:

~~The difference between compression skin friction and tension skin friction should be taken into account through the resistance factor, to be consistent with how this is done for the strength limit state (see Article C10.5.5.2.3).~~

10.6.1 General Considerations

10.6.1.1 General

Revise the 1st paragraph as follows

Provisions of this article shall apply to design of isolated, continuous strip and combined footings for use in support of columns, walls and others substructure and superstructure elements. Special attention shall be given to footings on fill, to make sure that the quality of the fill placed below the footing is well controlled and of adequate quality in terms of shear strength, swell or expansion potential and compressibility to support the footing loads.

C10.6.1.1

Revise 2nd paragraph as follows:

Spread footing should not be used on soil or rock conditions that are determined to be expansive, collapsible, or too soft or weak to support the design loads, without excessive movements, or loss of stability.

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10.6.1.3 Effective Footing Dimensions

Revises as follows:

For eccentrically loaded footings on soil, a reduced effective area, *B'* x *L'*, within the confines of the physical footing shall be used in geotechnical design for settlement and bearing resistance. The point of load application shall be at the centroid of the reduced effective area.

The reduced dimensions for an eccentrically rectangular footing on soil shall be taken as:

$$B' = B-2e_B \qquad (10.6.1.3\text{-}1)$$

$$L' = L- e_L$$

Where,

e_B = M_L/V = eccentricity parallel to dimension *B* (ft)

e_L = M_B/V = eccentricity parallel to dimension *L* (ft)

M_B = moment about the central axis along dimension B (kip-ft)

M_L = moment about the central axial along dimension L (kip-ft)

C10.6.1.3

Add the following sentence at the end of this article:

For additional guidance, see Munfakh (2001) and Article 10.6.3.2

10.6.1.4 Bearing Stress Distribution

Modify as follows:

When proportioning footings dimensions to meet settlement and bearing resistance requirements at all applicable limit states, the distribution of bearing stress ~~on the effective area~~ shall be assumed as:

- Uniform <u>over the effective area</u> for footing on soils, or
- Linearly varying, e.g. triangular or trapezoidal distribution as applicable, for footing on rock.

The distribution of bearing stress shall be determined as specified in Article 11.6.3.2.

Bearing stress distributions for structural design of footing shall be as specified in Article 10.6.5.

C10.6.1.4

For an eccentrically loaded footing on soils, the factored bearing resistance obtained based on the reduced dimensions *B'* and *L'* is compared with the total factored vertical load on the footing divided by the reduced footing dimension.

For an eccentrically loaded footing on rock, the factored bearing resistance obtained based on the actual footing dimensions is compared with the maximum bearing stress (Munfakh, 2001). The maximum bearing stress is obtained based on the conventional assumption of a rigid footing as specified in Article 11.6.3.2 for footings on rock.

10.6.1.6 Groundwater

Modify the last paragraph as follows:

The influences of groundwater ~~table~~ on the bearing capacity of soils or rocks, <u>the expansion and collapse potential of soils or rock,</u> and on the settlements of the structure should be considered. In cases where seepage forces are present, they should also be included in the analyses.

10.6.2.4.1 General

Modify the last paragraph as follows;

The distribution of vertical stress increase below ~~circular or~~ square and long rectangular footings, e.g., where $L>5B$ may be estimated using Figure 1.

C10.6.2.4.1

Insert the following text after the last paragraph:

<u>For eccentrically loaded footings on soils, replaced *L* and *B* in these specifications with the effective dimensions *L'* and *B'* respectively</u>.

10.6.2.4.2 Settlement of Footing on Cohesionless Soils

Modify the 1st sentence of the 3rd paragraph as follows:

The elastic half-space method assumes the footing ~~to be flexible and~~ is supported on a homogeneous soil of infinite depth.

Modify the last paragraph as follows:

In Figure 1, *N1* shall be taken as $(N_1)_{60}$, Standard Penetration Resistance, *N* (blows/ft), corrected for hammer energy efficiency and overburden pressure as specified in Article 10.4.6.2.4

C10.6.2.4.2

Modify the 6th paragraph as follows:

~~The stress distribution used to calculate elastic settlement assume the footing is flexible and supported on a homogeneous soil of infinite depth.~~ In Table 1, the β_z values for the flexible foundations correspond to the average settlement. The elastic settlement below a flexible footing varies from a maximum near the center to a minimum at the edge equal to about 50 percent and 64 percent of the maximum for rectangular and circular footing, respectively. For low values of L/B ratio, the average settlement for flexible footing is about 85 percent of the maximum settlement near the center. The settlement profile for rigid footing is assumed to be uniform across the width of the footing.

Modify the last sentence of the 8th paragraph as follows:

Therefore, in selecting the appropriate values for soil modulus, consideration should be given to the influences of soil layering, bedrock at shallow depth, and adjacent ~~footings~~ foundations.

10.6.2.4.3 Settlement of Footings on Cohesive Soils

Insert the following after the 1st paragraph:

Immediate or elastic settlement of footing foundations on cohesive soils can be estimated using Eq. 10.6.2.4.2-1 with appropriate value of the soil modulus.

Disregard the arrows in the Eqs. 10.6.2.4.3-2,3 and 4.

For eccentrically loaded footings, replaced B/H_c with B'/H_c in Figure 10.6.2.4.3-3.

C10.6.2.4.3

Add the following:

The specifications and commentary presented in Article 10.6.2.4.2 on the elastic half space method of estimating elastic settlement are also applicable to cohesive soils. For additional guidelines, see U.S. Department of the Navy (1986).

10.6.3.1.2a Basic Formulation

Modify Eq. 2a as follows:

$$\underline{q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + 0.5\gamma B N_{\gamma m} C_{w\gamma}} \quad (10.6.3.1.2a\text{-}1)$$

Delete the following text:

~~g = gravitational acceleration (ft/sec²)~~

10.6.3.1.2e Two-layered Soil System in Undrained Loading

Replace H with H_{s2} in Figure 10.6.3.1.2e-2.

C10.6.3.1.2e

Replace H with H_{s2} in Eqs. 5 and 6.

10.6.3.1.2f Two-layered Soil System in Drained Loading

Replace H with H_{s2} in Eq. 1

C10.6.3.1.2f

Replace H with H_{s2} in Eq. 1

10.6.3.1.3 Semiempirical Procedures

Modify title as follows:

10.6.3.1.3 Semi-empirical Procedures <u>for Cohesionless soils</u>

C10.6.3.1.3

Insert the following at the end:

<u>It is recommended that the SPT based method not be used</u>.

10.6.3.2 Bearing Resistance of Rock

10.6.3.2.1 General

C10.6.3.2.1

Modify the last sentence as follows:

The designer should verify adequate overall stability at the service limit state and size the footing based on eccentricity requirements at the strength limit state before checking the movements at the service limit state.

10.6.3.2.4 <u>Plate</u> Load Test

Where appropriate, <u>plate</u> load tests may be performed to determine the nominal bearing resistance of foundations on rock

10.6.3.4 Failure by Sliding

Replace Q_τ with R_τ in Figure 10.6.3.4-1.

10.7 DRIVEN PILES

10.7.4 Extreme Event Limit State

Delete the 4th paragraph as follows:

~~When designing for scour, the pile foundation design shall be conducted as described in Article 10.7.3.6, except that the base flood and resistance factors consistent with Article 10.5.5.3.2 shall be used.~~

10.8 DRILLED SHAFTS

10.8.4 Extreme Event Limit State

The provisions of Article 10.5.5.3 and 0.7.4 shall apply.

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